

ESTIMATING CORE RANGES: A COMPARISON OF TECHNIQUES USING THE COMMON BUZZARD (*BUTEO BUTEO*)

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ABSTRACT.—The need to describe the relative intensity with which an animal uses different parts of its home range has been recognized for at least half a century. Such descriptions are particularly important for wide-ranging raptors with home ranges covering a variety of habitats. In studies of many taxa, the description of internal range structure is addressed by describing a core range of most intensive use. However, there is still no broadly accepted definition of a core or method of objectively estimating core ranges. Here, we propose that a core range can be usefully defined by the exclusion of excursive activity with the assumption that behavior differs between core and excursive activities. Two methods of excluding excursive activity are presented for winter ranges of the Common Buzzard (*Buteo buteo*) in lowland U.K. The first involves subjective exclusion of outlying locations, using the outermost discontinuity in the utilization distribution (UD). Incremental Cluster Polygons are used to produce the UD because this method provides the closest spatial relationship to the animal locations and the most clearly defined discontinuities. The potential for error or bias in this subjective method may often be unacceptable, particularly for home ranges which do not have well-defined core areas. The second method is a new application of incremental cluster analysis that objectively excludes excursive locations. The objective and subjective approaches are compared, and implications of core range definition in habitat and sociality analysis of raptors are explored in the context of published analyses on raptors and other taxa.

KEY WORDS: *home range, core range, radiotelemetry, incremental cluster analysis, Buteo buteo.*

Estimación de rangos centrales: Una comparación de técnicas utilizando a *Buteo buteo*

RESUMEN.—La necesidad de describir la intensidad relativa en que un animal utiliza las diferentes partes de su rango de hogar ha sido reconocida por lo menos desde hace medio siglo. Estas descripciones son particularmente importantes para las aves de presa que tiene rangos amplios con una gran variedad de habitats. En los estudios de muchos taxones, la descripción de la estructura del rango interno es abordada mediante la descripción del rango central como el mas utilizado. No obstante, no existe aún una definición aceptada del centro o de un método para estimar en forma objetiva los rangos centrales. Aquí proponemos que un rango central puede ser definido en forma útil mediante la exclusión de las actividades de incursión. Dos métodos para excluir la actividad de incursión son presentados para los rangos de invierno de *Buteo buteo* en el Reino Unido.

[Traducción de César Márquez]

Radiotelemetry has been used to study raptors for nearly three decades, providing data for many aspects of ecological research (Kenward 1985a). However, improvement in the collection and analysis of data has been slower than the technical developments in radio-tracking (Lance and Watson 1980, Harris et al. 1990, Kenward 1992). The de-

scription of the intensity with which animals use different parts of their home ranges presents a fundamental problem (Hayne 1949). Animals generally live in a spatially heterogeneous environment in terms of food availability, nest and roost sites, density of competitors, and other factors. Therefore, they tend to have one or more core areas of

intensive use in their home ranges (Kaufman 1962) and it is likely that their behavior will differ in the core and outer areas of the home range. Many raptors are wide-ranging and their outer home-range boundaries may enclose habitat known to be avoided (e.g., Stahlecker and Smith 1993). Raptors may also make excursions from their usual range. Common buzzards (*Buteo buteo*), for instance, often make brief movements of up to 20 km during their first year (Walls and Kenward 1994), before returning to ranges typically less than 1.1 km in diameter (Walls and Kenward 1995). Therefore, an analysis method for core ranges should exclude excursive locations (Burt 1943) and areas within an outer home-range boundary that are avoided (White and Garrott 1990). A number of methods have been proposed for estimating range cores, but none are widely accepted. Therefore, comparisons between studies is generally not possible.

The process of finding a core range can be split into three stages: (1) the description of the internal range structure, giving nominal cores; (2) the choice of a percentage inclusion of radio locations that selects a biologically meaningful core for each individual; and (3) setting a standard core range (in terms of a standard percentage of locations) for a sample of animals to allow statistical comparison within the sample. Here, we present a comparison of techniques used to describe the core ranges of raptors.

COLLECTION OF DATA

Common Buzzards in southern Dorset, U.K. were instrumented with radio-tags at the nest just before fledging. Each radio-tag weighed 30 g and was mounted as a backpack with 6-mm-wide Teflon ribbon (Biotrack, 52 Furzebrook Rd., Wareham, U.K.). These tags had a life of up to 4 yr and a maximum range of 40 km from the ground and 80 km from the air. To avoid disturbance of the study animals, buzzard locations were determined by triangulation from roadsides. Error associated with the locations was estimated at about 100 m. Standard 30 location home ranges (three locations per d for 10 d [Kenward 1987]) were recorded for 122 buzzards from 1990–96. These included buzzards aged between 1 and 4 yr. Data were collected in the nonbreeding season after the main dispersal period, when the buzzards had settled in relatively stable ranges. Data were analyzed using a modified

version of RANGES V (Kenward and Hodder 1996).

DESCRIPTION OF RANGE STRUCTURE

Several different methods have been used for describing internal range structure. The efficacy of these methods can be judged by their conformation to the locations, including their ability to conform to multinuclear cores. A further major requirement is efficiency. To give time for data collection on a sufficient number of animals, most projects require an analysis method that can estimate the range structure from a minimum number of locations per animal. The grid cell approach (Siniff and Tester 1965, Ables 1969, Voigt and Tinline 1980, Samuel et al. 1985, Samuel and Green 1988) conforms to location distribution. However, this method may require more than 150 locations to calculate a stable home range that does not increase in size as more locations are added (Doncaster and Macdonald 1991). The tessellation technique proposed by Wray et al. (1992a) also requires a large number of locations. Contouring methods (Dixon and Chapman 1980, Worton 1989) stabilize with fewer than 50 locations. However, their accuracy of fit to the locations is influenced by dependency on an arbitrary grid and the use of parametric estimation functions (Spencer and Barrett 1984, Kenward 1992, Wray et al. 1992b). Ellipses (Jennrich and Turner 1969) give stability with even fewer locations but conform poorly to the locations and can only provide one nucleus. Polygon-based techniques have stable outer edges with 30 locations (Kenward 1982, Parish and Kruuk 1982, Kenward 1987); however, peeled convex polygons (Kenward 1985b, 1987) provide a poor fit to multinuclear or curved ranges (White and Garrott 1990). These problems may be avoided with Incremental Cluster Polygons (ICP) (Kenward 1987). ICP analysis is based on forming groups of locations and separating outliers. Convex polygons drawn around the clusters provide a range outline that is not influenced by a grid or the position of outlying locations (Kenward 1987). Also, the outlines produced by elimination of outlying locations stabilize at less than 50 locations (Kenward 1992). Therefore, we adopted ICP as the method for estimating internal range structure in this paper.

SELECTION OF A BIOLOGICALLY MEANINGFUL CORE SIZE

The outline methods discussed can provide nominal core areas at any percentage inclusion of

locations. The second problem is to select a core that has biological significance. In the literature, the selection of core areas of most intense use has been largely subjective (Kenward 1985b, Harris et al. 1990, Wauters and Dhont 1992), or even arbitrary (Mohr and Stumpf 1966, Anderson 1982, Wray et al. 1992b, Hohmann 1994). For instance, the core range has been defined as a 50% contour (Heikkilä et al. 1996) or a 95% ICP core (Hulbert et al. 1996) but there is no biological basis for this. The subjective approach commonly uses the utilization distribution (UD) which is the polygon or contour area plotted against the percentage inclusion of locations (Van Winkle 1975). Identification of a discontinuity in this plot indicates the point where outlying fixes are excluded (Kenward 1985b, 1987, Harris et al. 1990). ICP is particularly suitable for this method because it produces a stepped UD, unlike contour methods for which the plot tends to be smooth (Kenward 1987).

An objective method for estimating a core range has been proposed by Samuel et al. (1985). However, to achieve good conformity to the locations, their method depends on a large sample size of locations. In this paper, we analyze ICP ranges for buzzards to compare the subjective method (using the UD) with a new objective method for excluding outlying (excursive) locations.

SELECTION OF PERCENTAGE LOCATIONS TO BE INCLUDED IN CORE RANGES

Subjective Exclusion of Excursive Locations. When locations recorded for an animal include relatively long distance excursions (Fig. 1a), the outermost discontinuity on the slope of a utilization distribution can be very clearly defined (Fig. 1b). In such cases, it is easy to visually select the point on the UD curve that indicates the size of the Excursion-Excluded Core (EEC). However, other individuals may have less well-defined cores (Fig. 1c and 1d). In this case, it is difficult to decide whether there is a core at 95% or 100% inclusion of locations (Fig. 1d). EEC ranges were subjectively estimated from the UD curve for the ICP winter ranges of each of 122 buzzards we studied.

Objective Exclusion of Excursive Locations. The separation of excursions from core ranges is based on the assumption that behavior differs between excursive and core activity. For example, buzzards and Northern Goshawks (*Accipiter gentilis*) tend to fly for much of the time during excursions but make shorter, less frequent flights during more typ-

ical foraging (Kenward 1977, Walls and Kenward 1995). Therefore, if sufficient locations were recorded, it is likely that the nearest neighbor (NN) distances between locations would form two frequency distributions representing core and excursive activity. In these hypothetical distributions, the mean distance between NN locations in the core would be expected to be smaller than the mean of NN distances where at least one of the locations is excursive. In most animal location data sets excursions are relatively rare. Therefore, the frequency distribution of NN distances would be expected to be negatively skewed with the positive tail indicating excursive activity.

The frequency distribution of NN distances was examined in a subsample of 10 buzzard ranges. For each of the ranges, the NN distance was calculated for all the locations ($N = 30$). To compensate for differences in the frequency distributions of NN distances between ranges, the distances were standardized by dividing by h_i for range i where $h_i = \sqrt{\frac{1}{2}(\sigma_{xi}^2 + \sigma_{yi}^2)}$ and σ_{xi} and σ_{yi} are the standard deviations of the location coordinates for range i in the x and y directions (Worton 1989). As expected, the pooled frequency distribution of the standardized distances for all 10 ranges was highly negatively skewed, with many short distances and fewer longer distances (Fig. 2).

A transformation was sought that would highlight the excursive locations as outliers. There were only a small number of NN distances in each range; therefore, it was not possible to use tests of normality to seek an optimal transformation. Instead, we sought the transformation that minimized the coefficient of variation (SD/\bar{x}) for the frequency distribution of NN distances. The effect of a number of logarithmic, reciprocal, and exponential transformations was examined on each of the 10 ranges. The transformation which most frequently minimized the coefficient of variation was generally the negative exponential transformation to q , where $q = \text{EXP}(-0.5 (NN/h_i)^2)$. This is the Gaussian kernel function of Worton (1989). This transformation was therefore applied to all 122 buzzard ranges which were used to estimate cores with the subjective (UD) method. In order to separate the excursive locations in each range, minimum excursion distances (MED) were estimated. These were the lower $P = 0.05$ (MED 0.05) and $P = 0.01$ (MED 0.01) percentiles of the normal distribution fitted to the transformed NN distances. Clusters were then formed incrementally until the

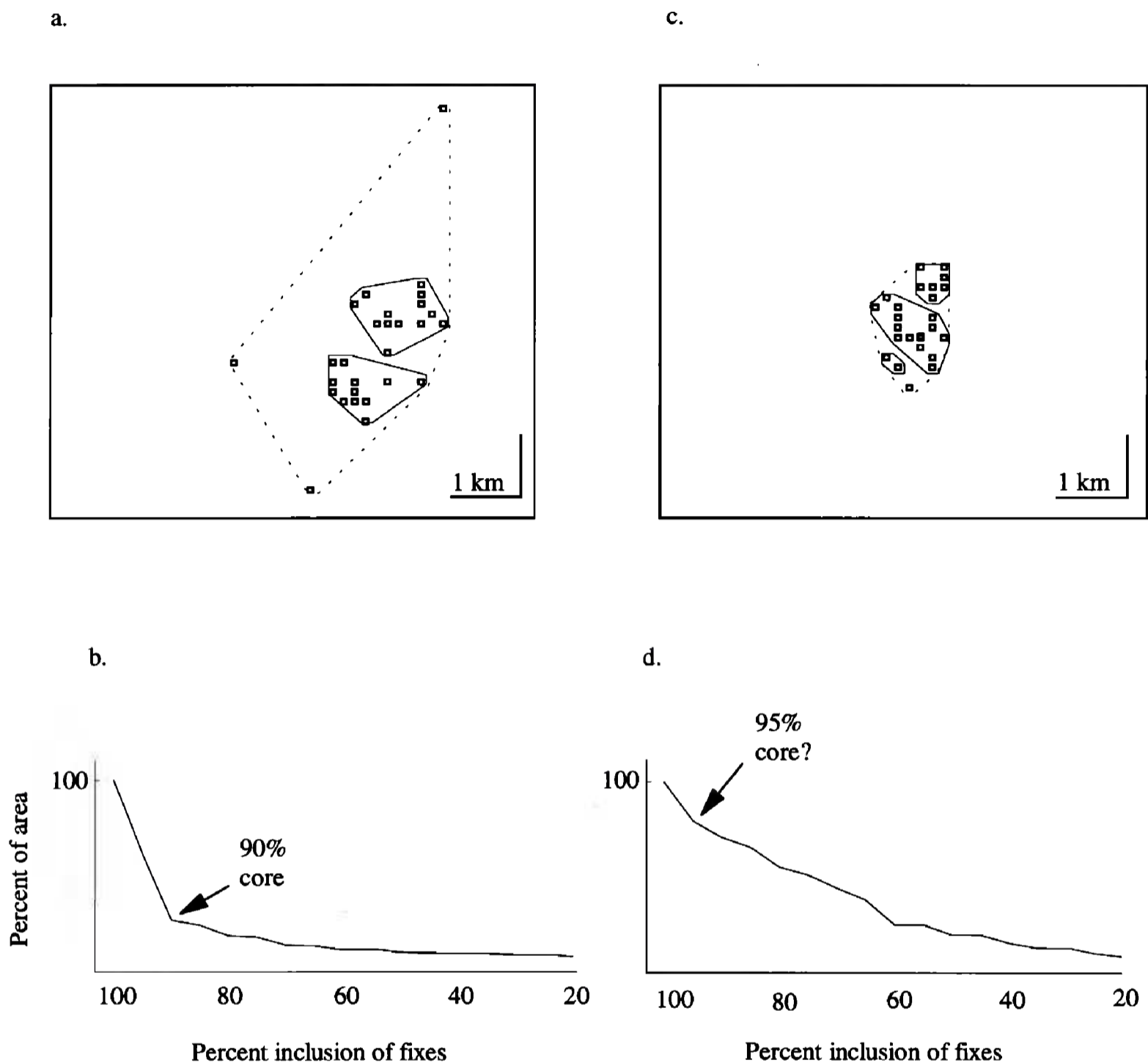


Figure 1. (a) Range areas and fixes of a juvenile male Common Buzzard (*Buteo buteo*) (JM906). Hatched line indicates the 100% Minimum Convex Polygon, solid line shows the 90% Incremental Cluster Polygons. (b) Utilization distribution for incremental cluster analysis (ICP) of the winter range of male buzzard (JM906). There is a clearly defined discontinuity in the curve at 90% inclusion of fixes. (c) Range areas and fixes of a juvenile male Common Buzzard (JM939). Hatched line indicates the 100% Minimum Convex Polygon, solid line shows the 90% Incremental Cluster Polygons. (d) Utilization distribution for incremental cluster analysis (ICP) of the winter range of juvenile male buzzard (JM939). There is no clearly defined discontinuity in the curve.

NN distance of the next fix to be added would have exceeded the MED. Any locations beyond this level were treated as excursive. The area of the convex polygon around the fixes in each cluster was summed to estimate the core range area.

Core percentages and areas obtained with the two probability levels of the MED method were compared with those estimated by the subjective (UD) method. Results obtained by the UD and the MED methods were similar when MED = 0.05 and often larger when using MED = 0.01. For instance,

buzzard JM939 had a 96% core at MED = 0.05, similar to the tentative core assigned with the UD method (Fig. 1d) but had a 100% core at MED = 0.01. Buzzard JM906 had a core at 90% inclusion of locations with the UD method (Fig. 1b) and the MED method (0.05 and 0.01). Core areas of the 122 buzzard ranges estimated by the UD method correlated well with core areas estimated using MED = 0.05 ($r = 0.82$, $N = 122$), and MED = 0.01 ($r = 0.89$, $N = 122$). However, the distribution of the points around the 1:1 line showed that with

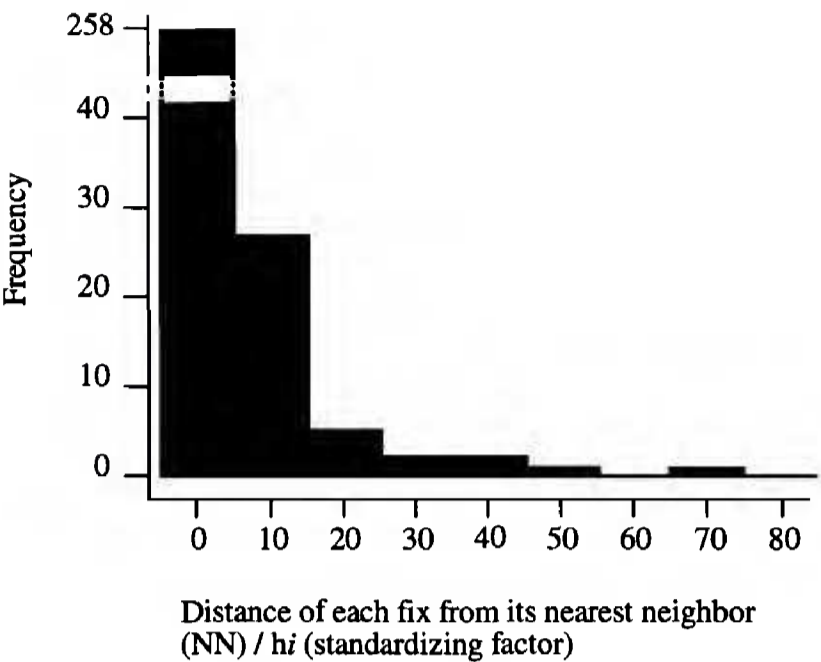


Figure 2. Frequency distribution of nearest neighbor (NN) interfix distances pooled from locations ($N = 296$) from 10 winter ranges of Common Buzzards. NN distances for each range are divided by a smoothing factor (h). Note that the y-scale is truncated.

MED = 0.05 all except one range were close to the line, whereas with MED = 0.01 the majority of core areas were larger than those estimated subjectively (Fig. 3a and 3b). Therefore, MED = 0.05 was considered appropriate for this sample of animals. This comparison showed that the MED method can give results which correlate well with the UD method, with the advantage that it is automated and does not involve subjective assessment for each animal.

SETTING A STANDARD CORE RANGE SIZE FOR A SAMPLE OF ANIMALS

If a core is required with a standard percentage of locations for a sample of animals, it is advisable to select a percentage at which cores have been estimated for most of the ranges. We recommend setting a standard where 95% of the ranges have been cored, because this permits one range in 20 to have many excursive locations without a disproportionate reduction in the sample core size. The resulting standard core percentage will only be larger than the core ranges of 5% of the sample. Therefore, few standard core ranges will include excursive locations. This is important because inclusion of excursive locations greatly increases the core range area, and thus the variance of areas in the sample. A larger proportion of the cores may be larger than the standard percentage. However, this has a small effect on sample variance, because

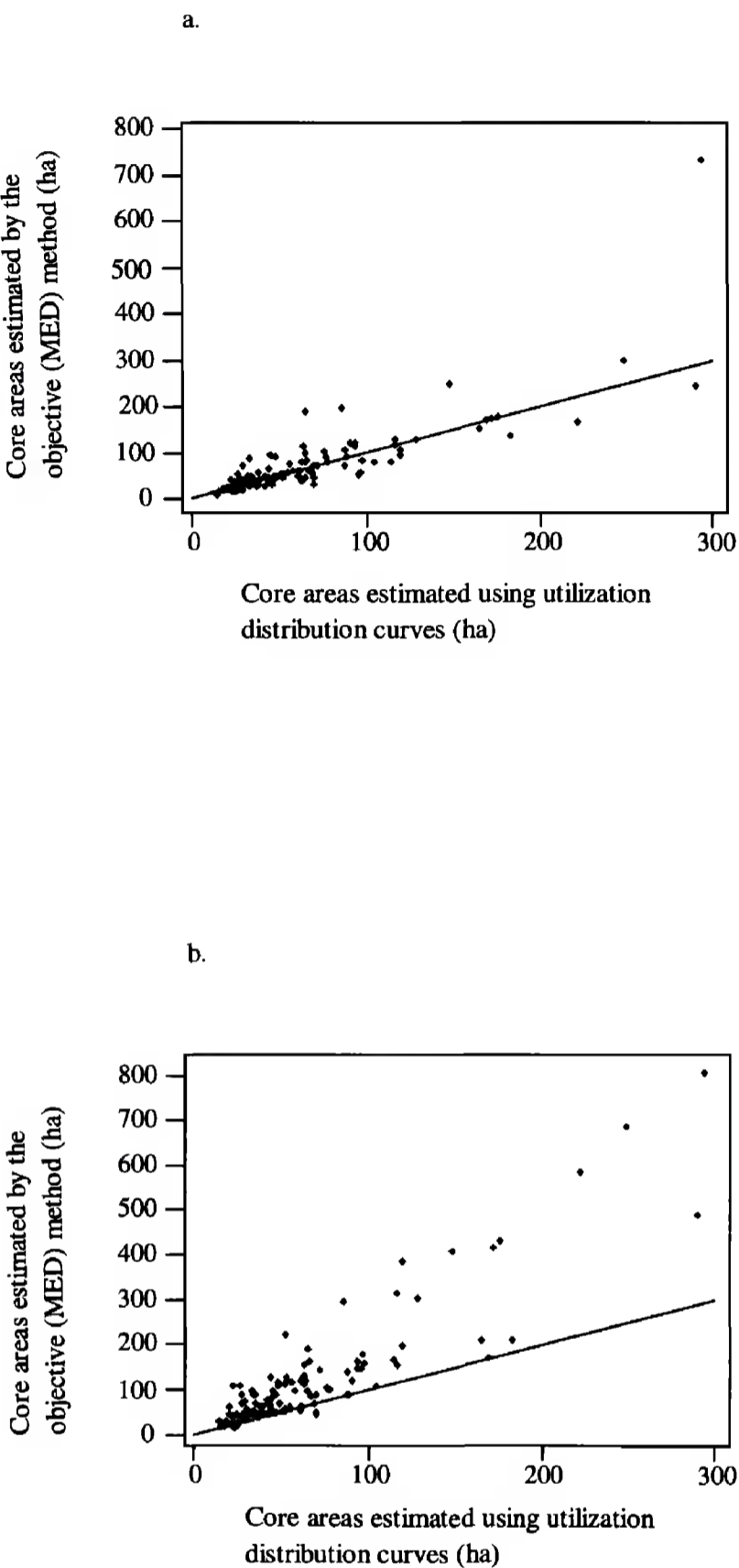


Figure 3. Comparison of core areas of 122 winter ranges of Common Buzzards obtained using subjective (UD) and objective (MED) methods. (a) with MED $P = 0.05$ and (b) with MED $P = 0.01$. The dotted line is the 1:1 line.

the removal of peripheral locations from these cores reduces the area much less than the removal of excursive locations.

This process was applied to the sample of 122 buzzard ranges. The number of ranges that had been cored increased as a function of the percent-

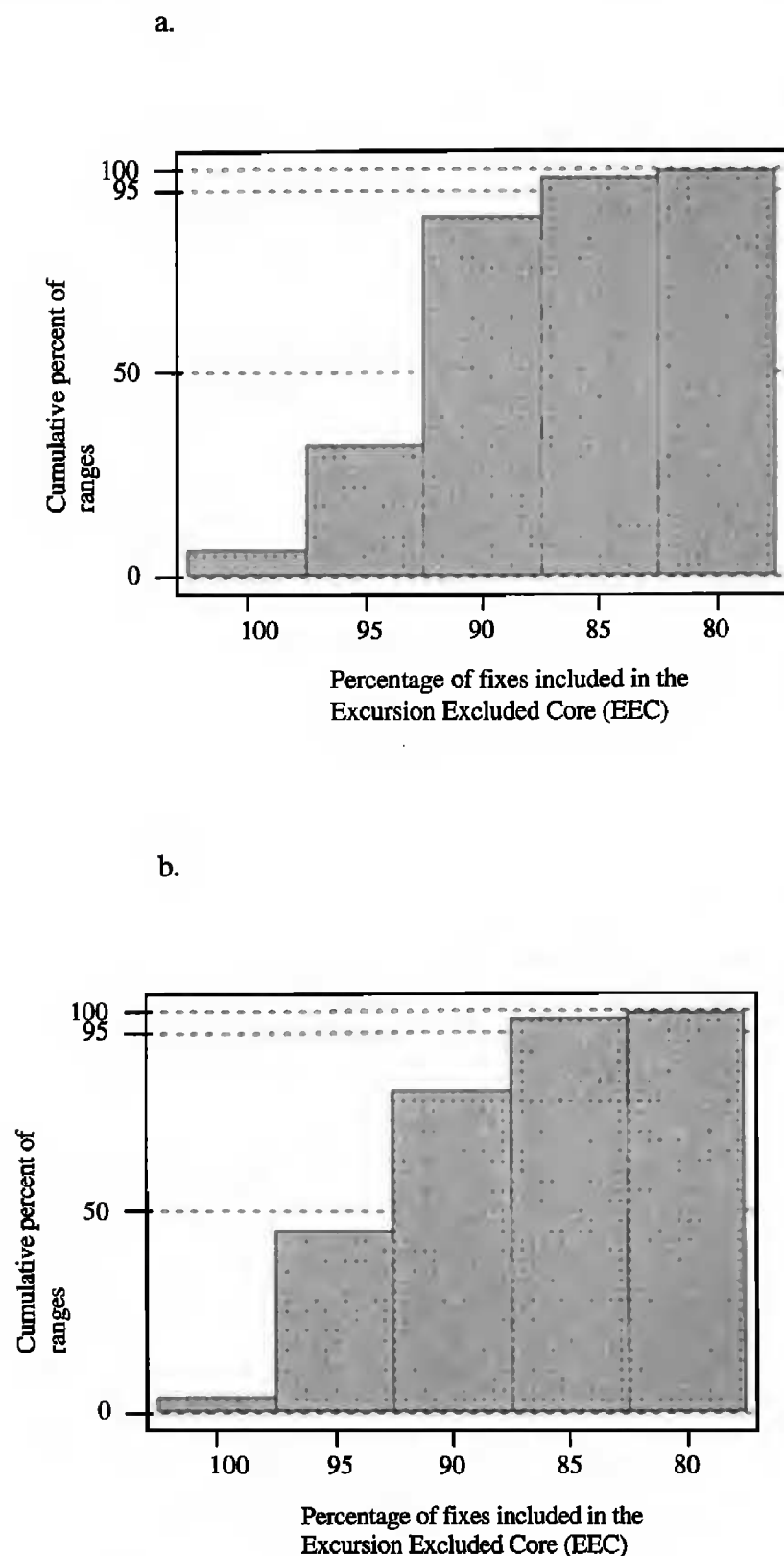


Figure 4. The core range size (percentage inclusion of locations) at which excursive activity is excluded by (a) subjective appraisal of the Incremental Cluster Polygon utilization distribution for buzzard home ranges ($N = 122$) and (b) by the Minimum Excursion Distance (0.05) for buzzard home ranges ($N = 122$).

age of core locations, for the objective (MED = 0.05) and subjective (UD) coring methods (Fig. 4a and 4b). In each case, cores had been estimated for 95% of the buzzard ranges when 15% of the locations were removed (i.e., the excursion excluded core contained 85% of the locations). With both methods, all the ranges reached cores that included at least 80% of the locations.

DISCUSSION

In analyses of radio-tracking data, the choice of method for estimating home range size and structure depends on the goal of the research (Voigt and Tinline 1980, Kenward and Walls 1994). Incremental Cluster Polygon analysis is particularly useful for identifying frequently used areas, as well as producing range structure statistics. Subjective (UD) and objective (MED) methods can be used to select the core ICP by excluding excursive locations. However, the subjective choice of core from the UD may be difficult, particularly for ranges that do not have a clearly defined core, and this has the potential to introduce error or even bias. For example, interpretation of the utilization distribution could be influenced by prior knowledge of a typical percentage inclusion for cores in the sample of animals. In contrast the MED method provides a means to objectively plot a boundary that delimits the usual area of the study animal. The transformation applied to the frequency distribution of NN distances and the choice of probability level of the MED need to be tested with other data sets. In the future, improvement in core range delineation might be achieved by plotting restricted edge polygons (Stickel 1954, Harvey and Barbour 1965, Voigt and Tinline 1980, Wolton 1985) rather than convex polygons around the clusters. Further work is also desirable to test the efficacy of this approach for data other than the standard 30-location range, especially data including variable numbers of locations or collected during the breeding season.

We suggest that excursion-excluded core ranges will provide important insights in behavioral ecology, especially in studies of sociality and habitat selection. In analyses of habitat use, a core range estimator allows data to be viewed at three spatial levels: overall availability, familiar area, and the usual area *sensu* Burt (1943). The study area (usually arbitrarily defined) can be used for overall availability. A range outline including all the locations such as the Minimum Convex Polygon (MCP) (Mohr 1947) or a probabilistic contour (e.g., Worton 1989) can delineate the familiar area of the animal. Finally, a biologically meaningful core can reveal the usual area. The importance of including internal range structure in studies of habitat use has been demonstrated in analyses using ICP cores. For example, in a study of Tawny Owls (*Strix aluco*) in woodland patches, Redpath

(1995) showed that the owls had much larger MCP ranges where woodland was fragmented in comparison to owls in continuous woodland. However, ICP cores (multinuclear polygons), were of a similar size in the different classes of woodland.

The estimation of a core range may also be extremely important in studies of behavioral interactions. Least overlap with conspecifics has been used to define core range boundaries (Auffenberg 1978, Christian et al. 1986). However, a core range that can show if individuals regularly use the same areas, is more ecologically informative. For instance, when resources are very concentrated, individuals may have overlapping home ranges, such as Northern Goshawks hunting near pheasant release pens (Kenward and Walls 1994). Conspecifics that have overlapping outer ranges may show avoidance in their core (Kenward 1985b, Samuel et al. 1985, Harris et al. 1990). Intraspecific differences in space use may also be masked by outer home range boundaries but revealed by the cores (Harris et al. 1990).

ICP cores selected by the MED for the buzzard give a biologically useful estimate of the core range. We anticipate that the method presented here will prove useful for raptors and for other taxa.

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LITERATURE CITED

- ABLES, E.D. 1969. Home range studies of red foxes *Vulpes vulpes*. *J. Mammal.* 50:108–120.
- ANDERSON, D.J. 1982. The home range: a new nonparametric estimation technique. *Ecology* 63:103–112.
- AUFFENBERG, W. 1978. Social and feeding behavior in *Varanus komodoensis*. Pages 77–491 in N. Greenberg and P.D. MacLean [EDS.], Behavior and neurology of lizards. DHEW, New York, NY U.S.A.
- BURT, W.H. 1943. Territoriality and home range as applied to mammals. *J. Mammal.* 24:346–352.
- CHRISTIAN, K., W.P. PORTER AND C. TRACEY. 1986. Core areas within the home ranges of land iguanas *Conolophus palidus*. *J. Herpetol.* 20:272–276.
- DIXON, K.R. AND J.A. CHAPMAN. 1980. Harmonic mean measure of animal activity measures. *Ecology* 61:1040–1044.
- DONCASTER, C.P. AND D.W. MACDONALD. 1991. Drifting territoriality in the red fox *Vulpes vulpes*. *J. Anim. Ecol.* 60:423–439.
- HARRIS, S., W.J. CRESSWELL, P.G. FORDE, W.J. TREWHELLA, T. WOOLLARD AND S. WRAY. 1990. Home-range analysis using radio-tracking data—a review of problems and techniques particularly as applied to the study of mammals. *Mammal Rev.* 20:97–123.
- HARVEY, M.J. AND R.W. BARBOUR. 1965. Home range of *Microtus ochrogaster* as determined by a modified minimum area method. *J. Mammal.* 46:398–402.
- HAYNE, D.W. 1949. Calculation of size of home range. *J. Mammal.* 30:1–18.
- HEIKKILÄ, R., K. NYGREN, S. HARKONEN AND A. MYKKANEN. 1996. Characteristics of habitats used by female moose in the managed forest area. *Acta Theriologica* 41:321–326.
- HOHMANN, U. 1994. Status specific habitat use in the Common Buzzard *Buteo buteo*. Pages 359–366 in B.-U. Meyburg and R.D. Chancellor [EDS.], Raptor conservation today. Proceedings of the IV world conference on birds of prey and owls, Berlin, Germany. Pica Press, East Sussex, U.K.
- HULBERT, I.A.R., G.R. IASON, D.A. ELSTON AND P.A. RACEY. 1996. Home-range sizes in a stratified upland landscape of two lagomorphs with different feeding strategies. *J. Appl. Ecol.* 33:1479–1488.
- JENNIRICH, R.I. AND F.B. TURNER. 1969. Measurement of a noncircular home range. *J. Theor. Biol.* 22:227–237.
- KAUFMAN, J.H. 1962. Ecology and social behaviour of the coati *Nasua narica* on Barro Colorado island, Panama. *Univ. Calif. Publ. Zool.* 60:95–222.
- KENWARD, R.E. 1977. Predation on released pheasants *Phasianus colchicus* by goshawks *Accipiter gentilis* in central Sweden. *Swed. Game Res.* 10:79–112.
- . 1982. Techniques for monitoring the behaviour of grey squirrels by radio. Pages 175–196 in C.L. Cheeseman and R.B. Mitson [EDS.], Telemetric studies of vertebrates. Academic Press, London, U.K.
- . 1985a. Raptor radio-tracking and telemetry. Pages 409–420 in I. Newton and R.D. Chancellor [EDS.], Conservation studies of raptors. ICBP, Cambridge, U.K.
- . 1985b. Ranging behaviour and population dynamics in grey squirrels. Pages 319–330 in R.M. Sibly and R.H. Smith [EDS.], Behavioural ecology: ecological consequences of adaptive behaviour. Blackwell Scientific, Oxford, U.K.
- . 1987. Wildlife radio-tagging equipment, field techniques and data analysis. Academic Press, London, U.K.
- . 1992. Quantity versus quality: programmed collection and analysis of radio-tracking data. Pages 231–244 in I.G. Priede and S.M. Swift [EDS.], Wildlife telemetry: remote monitoring and tracking of animals. Ellis Horwood, London, U.K.
- AND K.H. HODDER. 1996. Ranges V: an analysis

- system for biological location data. Natural Environment Research Council, U.K.
- AND S.S. WALLS. 1994. The systematic study of radio-tagged raptors: I. survival, home-range and habitat-use. Pages 303–316 in B.-U. Meyburg and R.D. Chancellor [EDS.], Raptor conservation today. Proceedings of the IV world conference on birds of prey and owls, Berlin, Germany. Pica Press, East Sussex, U.K.
- LANCE, A.N. AND A. WATSON. 1980. A comment on the use of radio-tracking in ecological research. Pages 355–359 in C.J. Amlaner and D.W. Macdonald [EDS.], A handbook on biotelemetry and radio-tracking. Pergamon Press, Oxford, U.K.
- MOHR, C.O. 1947. Table of equivalent populations of North American small mammals. *Am. Midl. Nat.* 37: 223–249.
- AND W.A. STUMPF. 1966. Comparison of methods for calculating areas of animal activity. *J. Wildl. Manage.* 30:293–304.
- PARISH, T. AND H. KRUUK. 1982. The uses of radio-tracking combined with other techniques in studies of badger ecology in Scotland. Pages 291–299 in C.L. Cheeseman and R.B. Mitson [EDS.], Telemetric studies of vertebrates. Academic Press, London, U.K.
- REDPATH, S.M. 1995. Habitat fragmentation and the individual: Tawny Owls *Strix aluco* in woodland patches. *J. Anim. Ecol.* 64:652–661.
- SAMUEL, M.D., D.J. PIERCE AND E.O. GARTON. 1985. Identifying areas of concentrated use within the home range. *J. Anim. Ecol.* 54:711–719.
- AND R.E. GREEN. 1988. A revised test procedure for identifying cores within the home range. *J. Anim. Ecol.* 57:1067–1068.
- SINIFF, D.B. AND J.R. TESTER. 1965. Aspects of animal movement and home range data obtained by telemetry. *Trans. N. Am. Wildl. Nat. Res. Conf.* 30:379–392.
- SPENCER, W.D. AND R.H. BARRETT. 1984. An evaluation of the harmonic mean measure for determining carnivore activity measures. *Acta Zool. Fenn.* 171:255–259.
- STAHLCKER, D.W. AND T.G. SMITH. 1993. A comparison of home range estimates for a Bald Eagle wintering in New Mexico. *J. Raptor Res.* 27(1):42–45.
- STICKEL, L.F. 1954. A comparison of certain methods of measuring ranges of small mammals. *J. Mammal.* 35: 1–15.
- VAN WINKLE, W. 1975. Comparison of several probabilistic home range models. *J. Wildl. Manage.* 39:118–123.
- VOIGT, D.R. AND R.R. TINLINE. 1980. Strategies for analysing radio-tracking data. Pages 387–404 in C.J. Amlaner and D.W. Macdonald [EDS.], A handbook on biotelemetry and radio-tracking. Pergamon Press, Oxford, U.K.
- WALLS, S.S. AND R.E. KENWARD. 1994. The systematic study of radio-tagged raptors: II. sociality and dispersal. Pages 317–324 in B.-U. Meyburg and R.D. Chancellor [EDS.], Raptor conservation today. Proceedings of the IV world conference on birds of prey and owls, Berlin, Germany. Pica Press, East Sussex, U.K.
- AND ———. 1995. Movements of radio-tagged Common Buzzards *Buteo buteo* in their first year. *Ibis* 137:177–182.
- WAUTERS, L. AND A.A. DHONT. 1992. Spacing behaviour of red squirrels, *Sciurus vulgaris*: variation between habitats and the sexes. *Anim. Behav.* 43:297–311.
- WHITE, G.C. AND R.A. GARROTT. 1990. Analysis of wildlife radio tracking data. Academic Press, San Diego, CA U.S.A.
- WORTON, B.J. 1989. Kernel methods for estimating the utilization distribution in home range studies. *Ecology* 70:164–168.
- WOLTON, R.J. 1985. The ranging and nesting behaviour of wood mice *Apodemus sylvaticus* (Rodentia: Muridae), as revealed by radio-tracking. *J. Zool.* 206:203–224.
- WRAY, S., W.J. CRESSWELL AND D. ROGERS. 1992a. Dirichlet tessellations: a new nonparametric approach to home range analysis. Pages 247–255 in I.G. Priede and S.M. Swift [EDS.], Wildlife telemetry: remote monitoring and tracking of animals. Ellis Horwood, London, U.K.
- , W.J. CRESSWELL, P.C.L. WHITE AND S. HARRIS. 1992b. What, if anything is a core area? An analysis of the problems of describing internal range configurations. Pages 256–271 in I.G. Priede and S.M. Swift [EDS.], Wildlife telemetry: remote monitoring and tracking of animals. Ellis Horwood, London, U.K.

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